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(54) **Projector with liquid crystal light valve using light emitting diodes of the three primary colours**

(57) A compact and energy efficient projection display can be made by starting with relatively pure red, green, and blue light sources. Each light source includes at least one light emitting diode 12_1, 12_2, 12_3. The output beams of the colored light sources are received by at least one spatial light modulator (18). The modulated output beams are collimated and combined. A projection lens (22) receives the collimated and combined output beams and directs them towards a projection screen (24). All of the above may be contained in a housing to provide a compact and lightweight projection display.

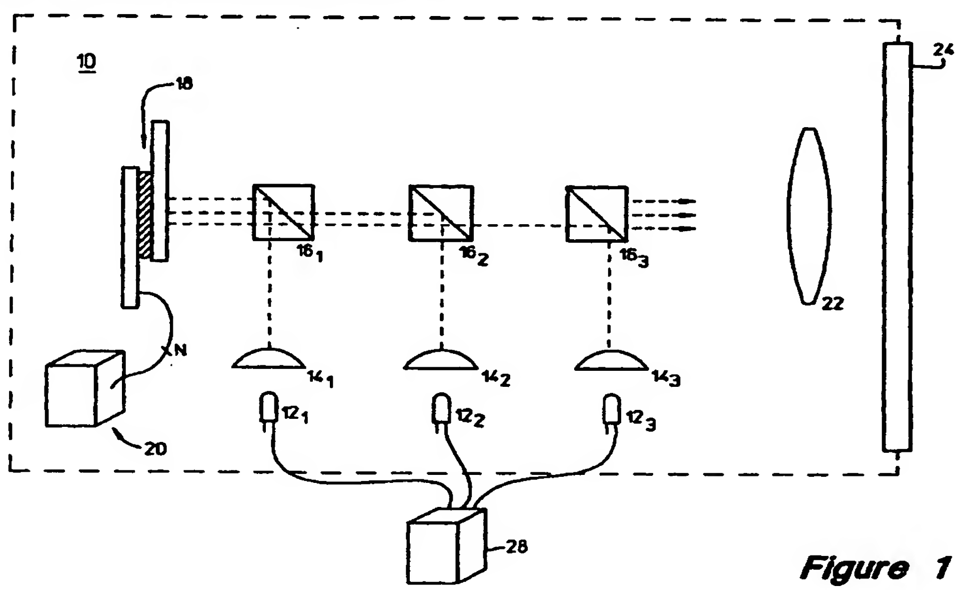

Figure 1

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Description

Field f the Invention

The invention is directed towards the field of projection displays. In particular, the invention relates to the manufacture of rear projection flat panel displays.

BACKGROUND OF THE INVENTION

Real image displays can be separated into three categories: cathode ray tubes (CRT), flat panel displays, and projection displays. Currently, CRT displays range from 1-40 inches along the image diagonal. These displays have good image quality and can be manufactured economically. The shape of the display requires a depth that can exceed the length of the image diagonal for high resolution graphic displays. The displays are bulky, especially for sizes above 20 inches because the wall thickness of the glass must be increased to withstand the atmospheric pressure. CRTs are popular in the desktop monitor market where the common length of the image diagonal is 14-17 inches.

Flat panel displays are used in many portable applications. They are thin and light in weight but have an image quality that is inferior to the CRT. At this time, the majority of displays are used in applications requiring 2-12 inches along the image diagonal. Flat panel displays are more costly to manufacture than the CRTs.

As a result, display applications that require an image size above 40 inches are dominated by projection displays: either front or rear. Both technologies can create a image by one of two methods: using three small high brightness monochromic CRTs for red, green, ad blue (RGB) or creating a color image via a spatial light modulator. These projection systems have low image brightness and are costly to manufacture.

It is not economical to reduce the conventional rear projection display to 17-20 inches along the image diagonal. The cost of the light valve is dominated by the drive circuitry. To illustrate, the drive circuitry of an XGA display (768x1024x3) is approximately $120 regardless of the screen size. A 70W metal halide arc lamp capable or producing 5000 lumens with its corresponding power supply, ballast, and hot re-ignition capability are required. The total cost is prohibitive and unattractive compared to the OEM cost of a 17 inch CRT.

SUMMARY OF THE INVENTION

A compact, light weight, and energy efficient projection display can be made by starting with relatively pure red, green, and blue light sources. The output beams of the colored light sources are received by at least one spatial light modulator. The modulated output beams are collimated and combined. A projection lens receives the collimated and combined output beams and directs them towards a projection screen. All of the above may be contained in a housing t provide a compact and lightweight projection display.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a preferred embodiment of the projection display.
Figure 2 illustrates an alternate embodiment of the present invention.
Figure 3 illustrates another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a light weight and compact projection display that is based on a spatial light modulator, typically a 1 cm^2 CMOS IC that is in direct contact with a ferro-electric liquid crystal material. Light transmitted through the liquid crystal material will rotate as a function of its plane of polarization with respect to the local surface voltage of the IC. Illuminating the LC/IC cell with consecutive flashes of red, green, or blue light from three separate LEDs creates a color-sequential image of the surface voltage of the IC.

The address circuitry is buried in the 1 cm^2 IC. All display information is sent to the IC on one or several high speed I/O lines. The IC/LCD combination is equivalent to a reflective active matrix liquid crystal display (AMLCD) light valve at much lower cost and higher performance. For instance, the transmissive design of an AMLCD light valve blocks 60% of the light due to the shadowing of metal lines and transistors. In contrast, the reflective cell has estimated losses of only 20%, mainly reflective losses from the aluminum pads covering th IC surface. By using sequentially strobed RGB light sources instead of a white light source, the more than 75% light loss in the color filter is also eliminated.

The pres nt invention, a rear projection display using a spatial modulator and three LED power sources can be optically fficient.

Table 1

	Conventional Design (Prior Art)	LED Design
Collimation	40%	60%
Polarizer	50%	50%
Rect/Circular Conversion	70%	70%
Color Filters	25%	100%
Valve Aperture	40%	80%
Misc. Refl./Absorption	60%	60%
Total	0.8%	10%

Table 1 illustrates the optical efficiency of a rear projection system based on conventional design and LED design of the present invention. Flux exiting the front surface of the screen, ϕ_{exit}, is defined as follows:

$$\phi_{exit} = BA\Omega$$

A is the area of the screen and B is the brightness of the desired Lambertian light distribution. If the screen has a gain g of 1.5 by reducing the angular distribution below a Lambertian distribution, then the exiting flux is:

$$\phi_{exit} = BA\Omega / g$$

For a high resolution desktop monitor, the brightness required is 100 cd/m^2. A 17 inch monitor has an image area of 25x30 cm^2 or A= $0.075m^2$. Because a desktop monitor may have a smaller viewing angle than a comparable sized television, the screen gain may be selected to be g=2. For these assumptions, the exit flux is computed to ϕ_{exit}= 12 lm. For an optical system design having an overall efficiency of 10%, a source flux of ϕ_{source}= 120 lm is required. This flux may be distributed over all three sources as follows:

Red	30 lm
Green	75 lm
Blue	15 lm

Figure 1 illustrates a preferred embodiment of a projection display 10 that includes three light emitting diodes 12_1, 12_2, 12_3, emitting a red, green, and blue light beam, respectively. Each light beam is received by a collimator 14_1, 14_2, 14_3. Each collimated light beam passes through a polarizing beam splitter 16_1, 16_2, 16_3. A spatial light modulator 18, having MxN pixels, modulates the split beams. The spatial light modulator 18 is controlled by a display driver 20. A projection lens 22 receives the modulated beams and directs them towards a projection screen 24, positioned at the front of the housing 26. A sequence controller 28, attached to the three light sources, controls the red, green, and blue light beams. The spatial modulator and the three light sources are connected to a power supply (not shown).

The red, green, and blue light emitting diodes, in combination, have a luminous flux of 10-1000 lm. It is preferred that the approximate flux ratio is 65% green, 25% red and 10% blue light.

The housing may optionally include at least two folding mirrors to receive the red, green, and blue light beams and to fold the red, green, and blue light beams. The folding mirrors allow the housing to be compact.

In this embodiment, the color subframes are sequential.

Figure 2 illustrates another embodiment of the present invention. There are three spatial modulators 18_1, 18_2, 18_3, one for each light beam to allow for parallel color subframes. In this embodiment, the color subframes are parallel.

Figure 3 illustrates another embodiment of the present invention. The multiple light emitting diodes shown in Figure 1 are replaced by a single light source 12. The single light includes light emitting diodes on a unitary substrate that emit red, green, and blue light. Ther is only one light path in the system as contrasted to the embodiments shown in Figures 1 and 2.

Claims

1. A projection display (10) comprising:

    red, green, and blue light units, each light unit includes,

        at least one light emitting diode (12_1,12_2,12_3) that emits a light beam,,
        a collimator (14_1,14_2,14_3) optically connected to the light source, producing a collimated light beam, and
        a beam splitter (16_1,16_2,16_3), optically connected to the collimator, generating a split beam;

    a spatial light modulator (18), having MxN pixels, optically connected to the beam splitters of the red, green, and blue light units;
    a projection lens (22), optically connected to the spatial light modulator, operative to focus the red, green, and blue light beams;
    a projection screen (21), optically connected to the projection lens;
    a drive circuit (28,20), connected to the spatial light modulator, being operative to generate color subframes;
    a power supply, connected to the spatial modulator and the red, green, and blue light units; and
    a housing that contains the red, green, and blue light units, the spatial light modulator, the projection lens, the projection screen, the control circuitry, and the power supply.

2. A projection display, as defined in claim 1, wherein any one of the red, green, and blue light sources is an array of N light emitting diode chips, where N ≤ 10, the array having a diameter of ≤ 3mm.

3. A projection display, as defined in claim 2, wherein any one of the red, green, and blue light sources further comprises:

    a reflector that surrounds the array of light emitting diode; and
    an immersion lens, receiving light from the array of light emitting diodes, operative to pre-collimate the light into a solid angle of 3 steradians or less.

4. A projection display, as defined in claim 3, wherein the array of light emitting diodes has an apparent source size less than 5 mm in diameter.

5. A projection display, as defined in claim 1, wherein any one of the red, green, and blue light sources further comprises:

    a reflector that surrounds the light emitting diode; and
    an immersion lens, receiving light from the light emitting diode, operative to pre-collimate the light into a solid angle of 3 steradians or less.

6. A projection display, as defined in claim 5, wherein the light emitting diode has an apparent source size, after magnification, less than 5 mm in diameter.

7. A projection display, as defined in claim 1, wherein the red, green, and blue light emitting sources have a combined luminous flux of 10-1000 lm with an approximate ratio of 65% green, 25% red and 10% blue light.

8. A projection display, as defined in claim 2, wherein one of the red, green, and blue light emitting diodes is a laser.

9. A projection display, as defined in claim 8, wherein the laser is a frequency-doubled Nd:YAG laser that emits the green light beam.

10. A projection display, as defined in claim 1, further comprising:

    at least two mirrors, that receive the red, green, and blue light beams, operative to fold the red, green, and blue light beams.

11. A projection display, as defined in claim 1, further comprising:

three spatial light modulators, each spatial light modulators receiving one of the red, green, and blue light beams, respectively; and

wherein the drive circuit generates the color subframes in parallel.

12. A projection display, as defined in claim 1, wherein the drive circuit generates the color subframes sequentially.

13. A projection display comprising:

a light unit that includes,

at least one red, one green, and one blue light source (12_1,12_2,12_3) on a unitary substrate, wherein the red, green, and blue light sources are independently switched, and

a collimator (14), optically connected to the red, green, and blue light source, producing collimated red, green, and blue beams;

a beam splitter(16), receiving the collimated red, green, and blue beams, operative to output split red, green, and blue beams;

a spatial light modulator (18), having MxN pixels, optically connected to the beam splitter;

a projection lens (22), optically connected to the spatial light modulator, being operative to focus the red, green, and blue beams;

a drive circuit (20), connected to the spatial light modulator, being operative to generate color subframes;

a power supply, connected to the spatial light modulator and the light unit; and

a housing that contains the light unit, the spatial light modulator, the projection lens, the projection screen, th control circuitry, and the power supply.

14. A projection display, as defined in claim 13, wherein the light unit generates a white light comprised of 25% red, 60% green, and 15% blue light.

15. A projection display, as defined in claim 13, wherein the red, green, and blue light sources are a single array of N light emitting diodes, wherein N is less than 10 and the array having a diameter of ≤ 3mm.

16. A projection display, as defined in claim 15, wherein the red, green, and blue light sources further comprise:

a reflector that surrounds the array of light emitting diodes; and

an immersion lens, receiving light from the array of light emitting diodes, operative to pre-collimate the light into a solid angle of 3 steradians or less.

17. A projection display, as defined in claim 16, wherein the array of light emitting diodes has an apparent source size, alter magnification, of less than 5 mm in diameter.

18. A projection display, as defined in claim 13, wherein the red, green, and blue light sources have a combined luminous flux of 10-1000 lm with an approximate ratio of 65% green, 25% red and 10% blue light.

19. A projection display, as defined in claim 13, wherein the drive circuit generates the color subframes sequentially.

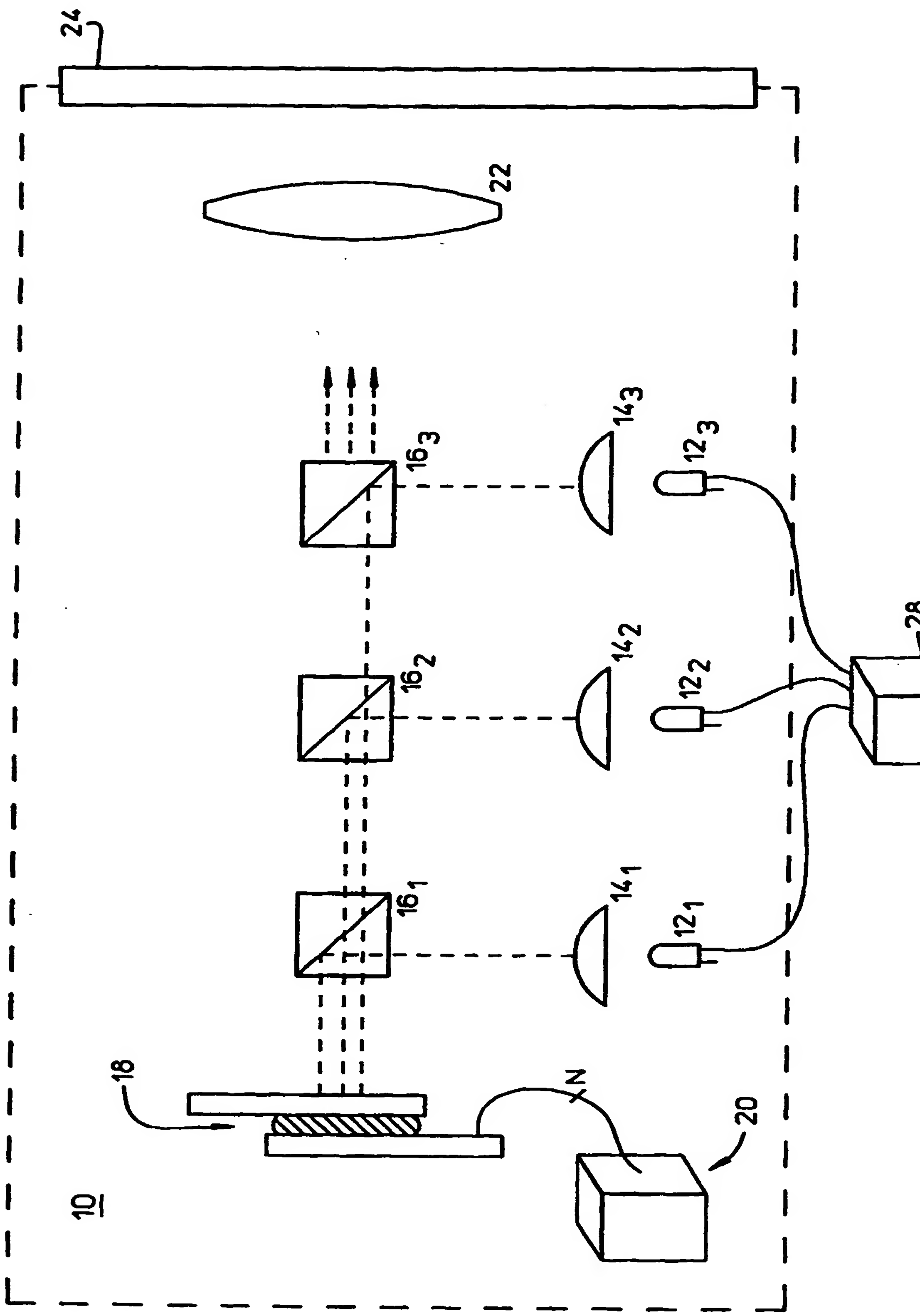

Figure 1

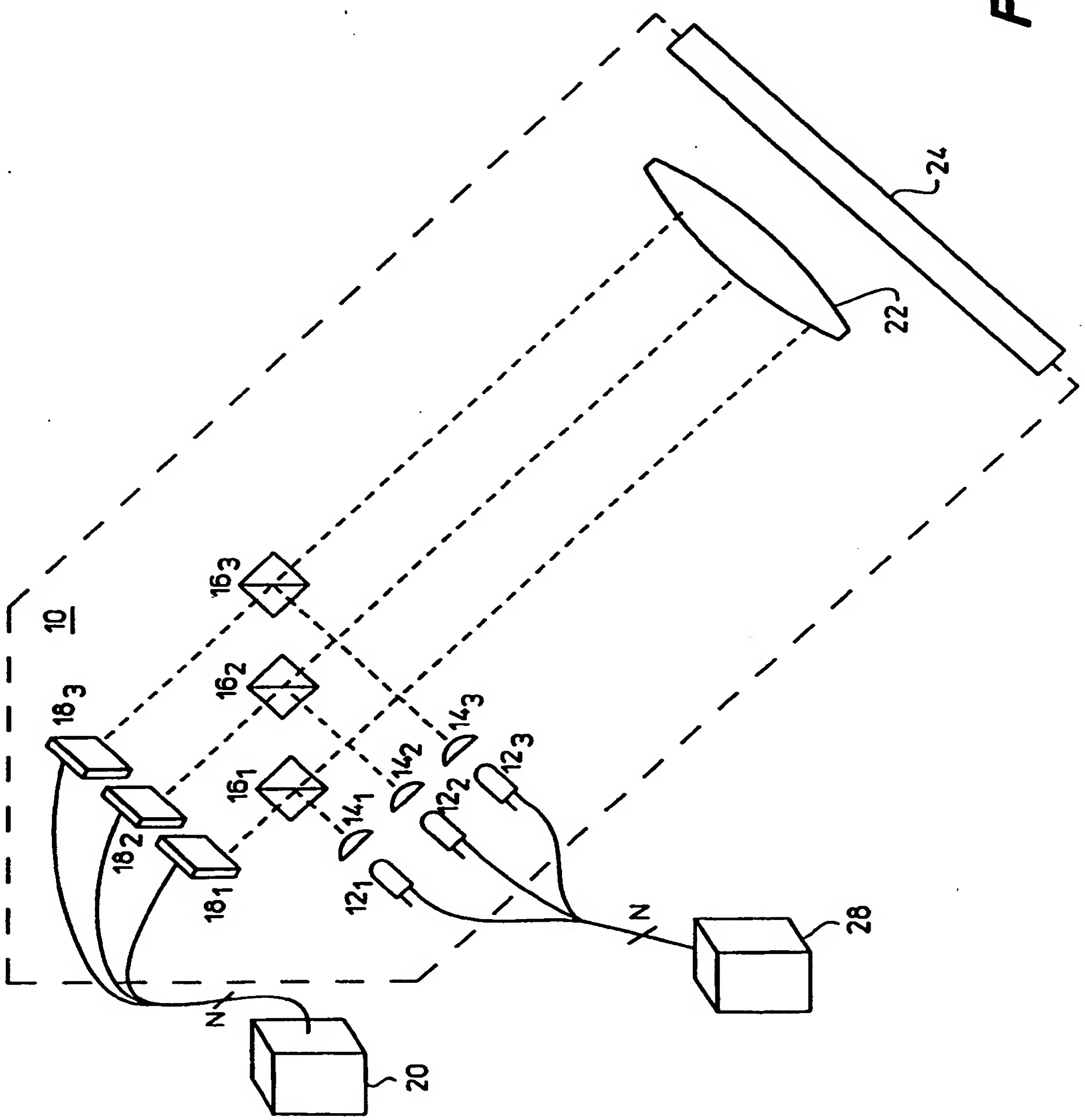

Figure 2

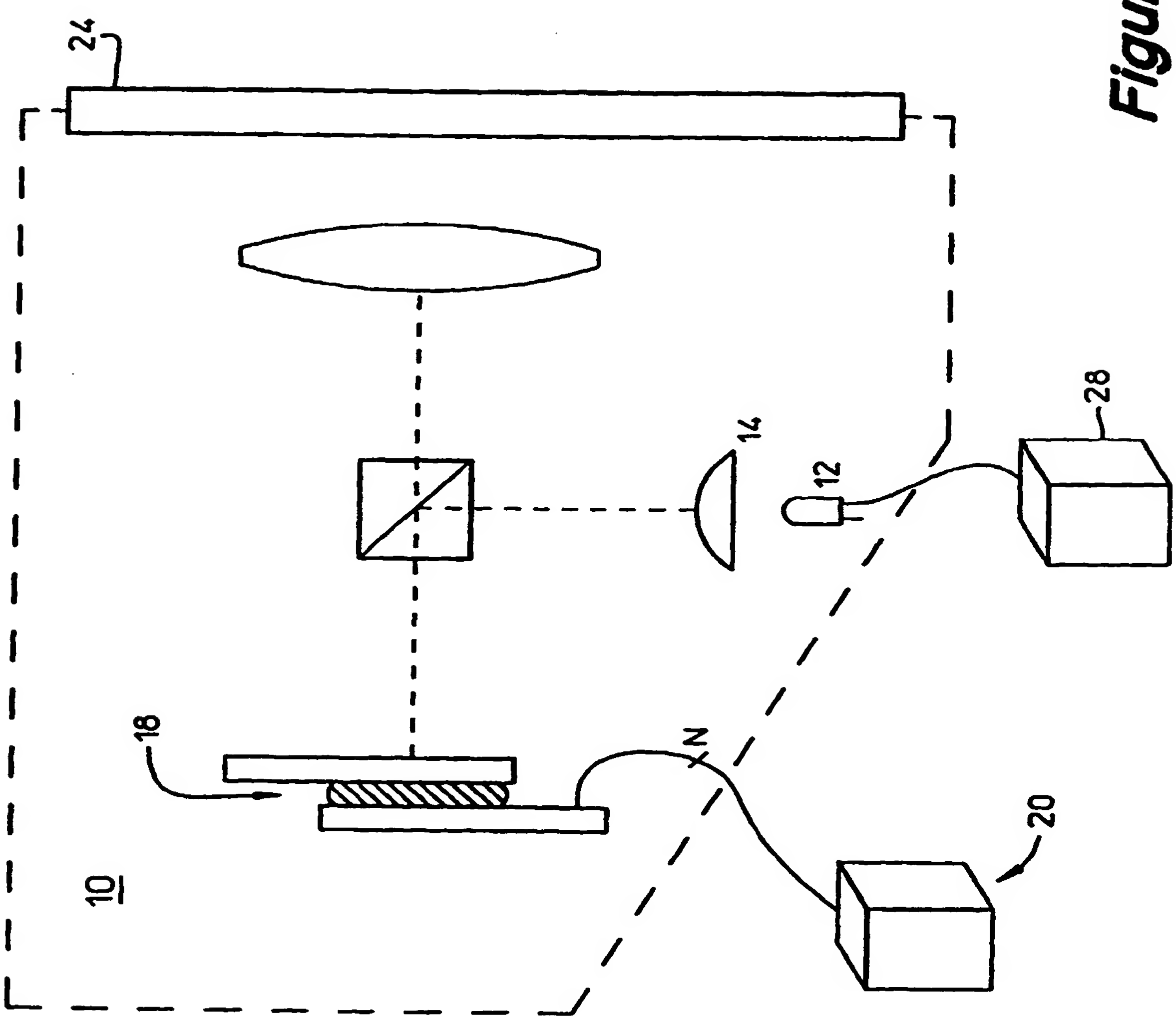

Figure 3

European Pat nt Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 2382

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	EP 0 573 925 A (HUGHES AIRCRAFT CO) 15 December 1993 * page 3, line 40 - page 4, line 15; figure 1 *	1-19	H04N9/31 G02B27/28
Y	US 5 467 154 A (FANTONE STEPHEN D ET AL) 14 November 1995 * claim 1; figures 10,11 *	1,13	
Y	ANONYMOUS: "Liquid Crystal Display Three Panel Projector Using Three Primary Colors Light Emitting Diode Light Sources" IBM TECHNICAL DISCLOSURE BULLETIN, vol. 40, no. 4, April 1997, pages 201-206, XP002079650 New York, US * the whole document *	1,13	
Y	WO 97 16679 A (HEWLETT PACKARD CO ;HAITZ ROLAND H (US)) 9 May 1997 * page 2, line 15 - page 8, line 24; figures 1-3 *	1-19	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	MOLZOW W -D ET AL: "ACTIVE SILICON CMOS ADDRESSING MATRICES FOR LIGHT-VALVE PROJECTION DISPLAYS" DISPLAYS, vol. 16, no. 1, 1 January 1995, pages 21-26, XP000510888 * page 21, right-hand column, line 15 - page 23, left-hand column, line 22 *		H04N G02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	6 October 1998	Lerbinger, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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